Sea ice conditions in the Baltic Sea and the impact for offshore wind farm foundations

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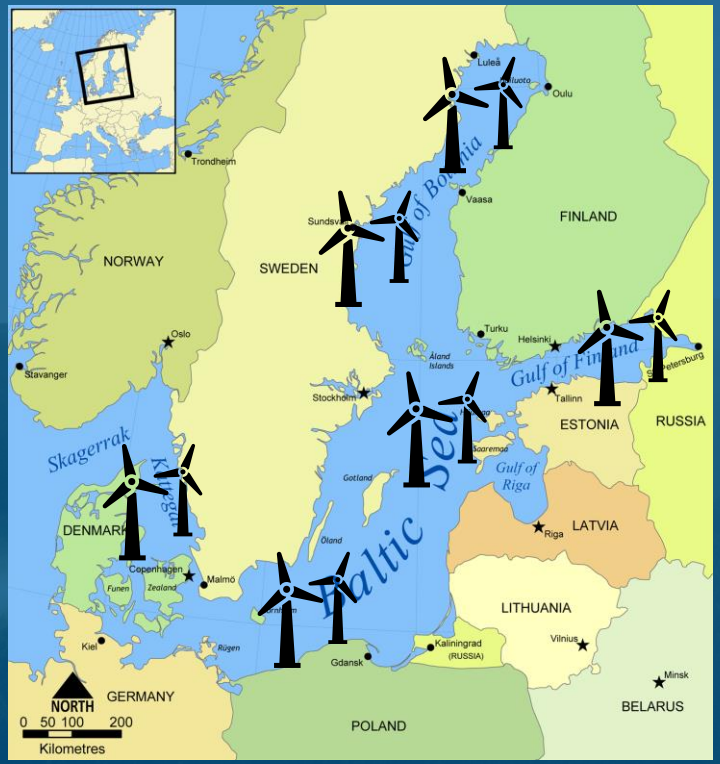
The Baltic Sea

“The Baltic Sea holds an incredible potential for offshore wind in Europe, and could host as much as 93 GW by 2050, up from 2.2 GW today.” (WindEurope, 2020)



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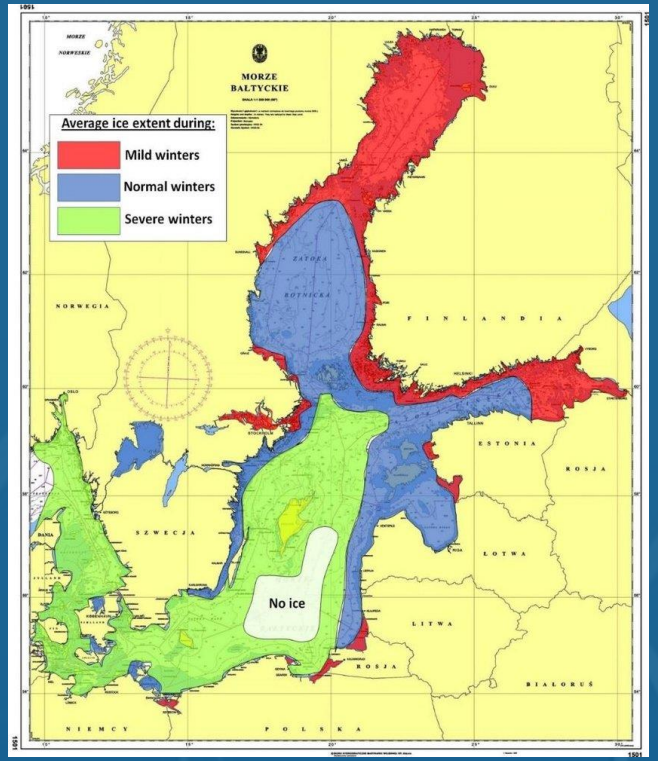
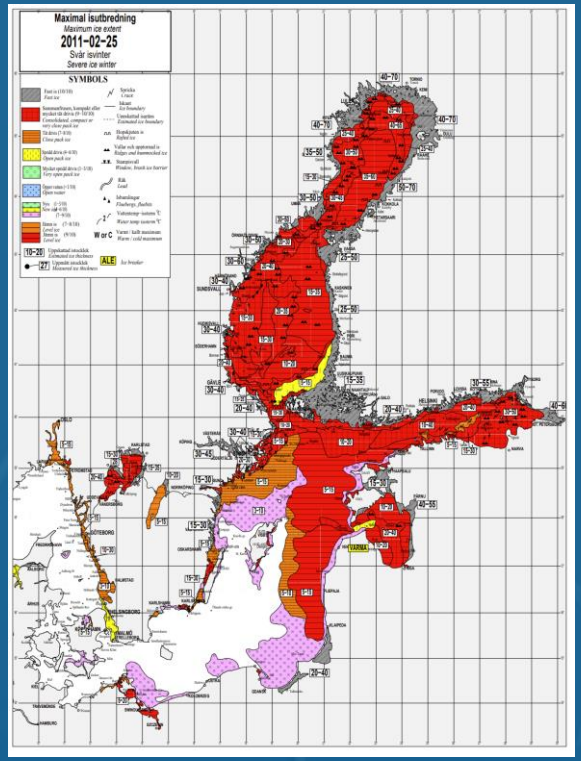
Presence of sea ice





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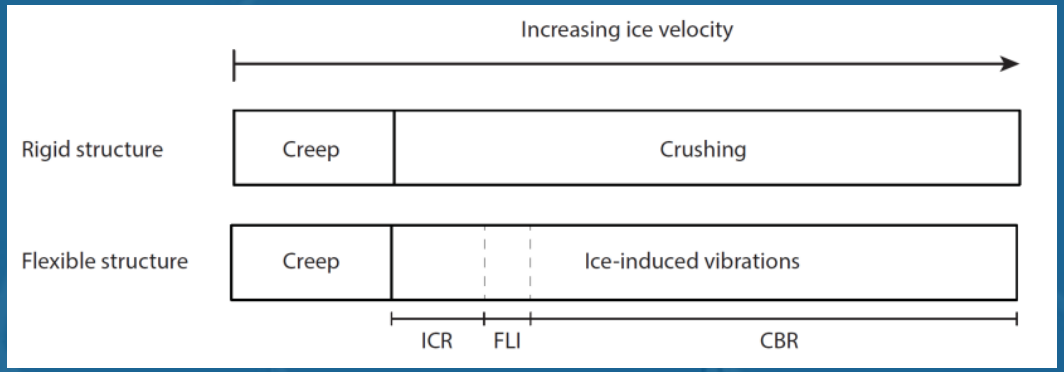
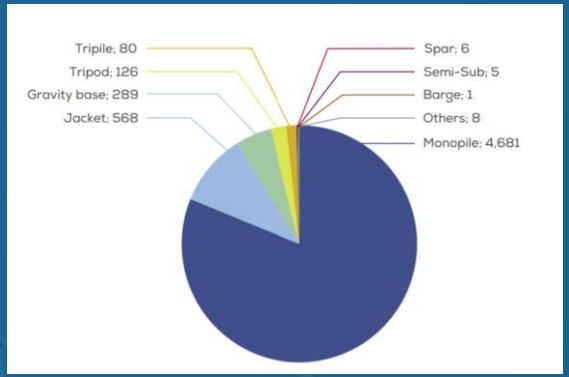
Ice-structure interaction

- Based on relative rigidity of the structure and the ice speed different types of interaction may develop:
  - Intermittent crushing (ICR)
  - Frequency lock-in (FLI)
  - Continuous brittle crushing (CBR)





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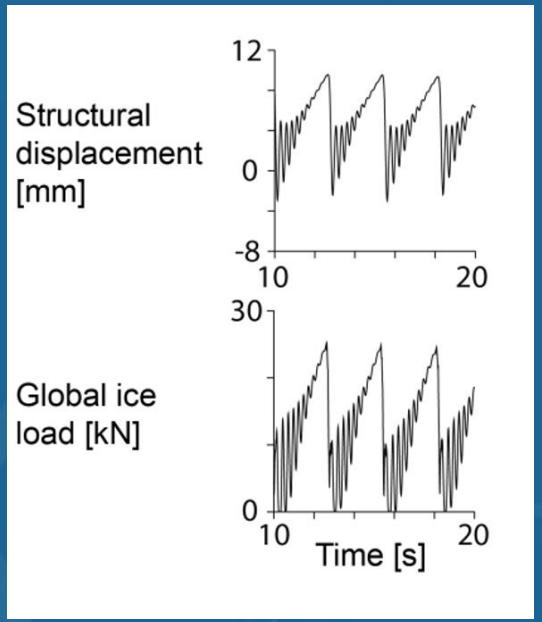
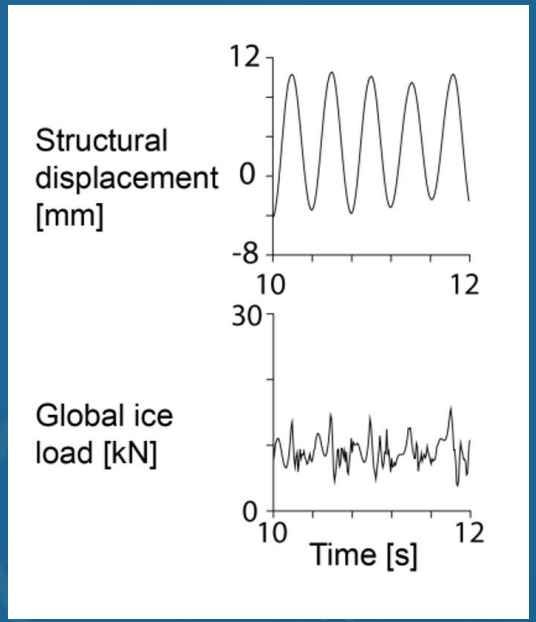
Ice-structure interaction

- Intermittent crushing:



- Frequency lock-in:



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Intermittent crushing

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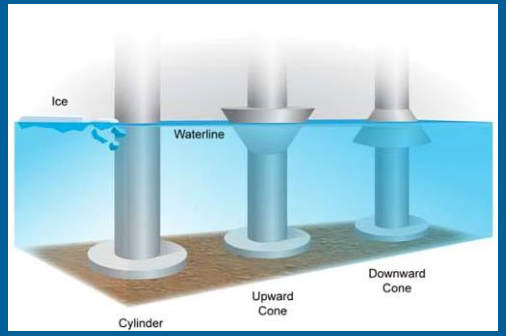
Alternative options

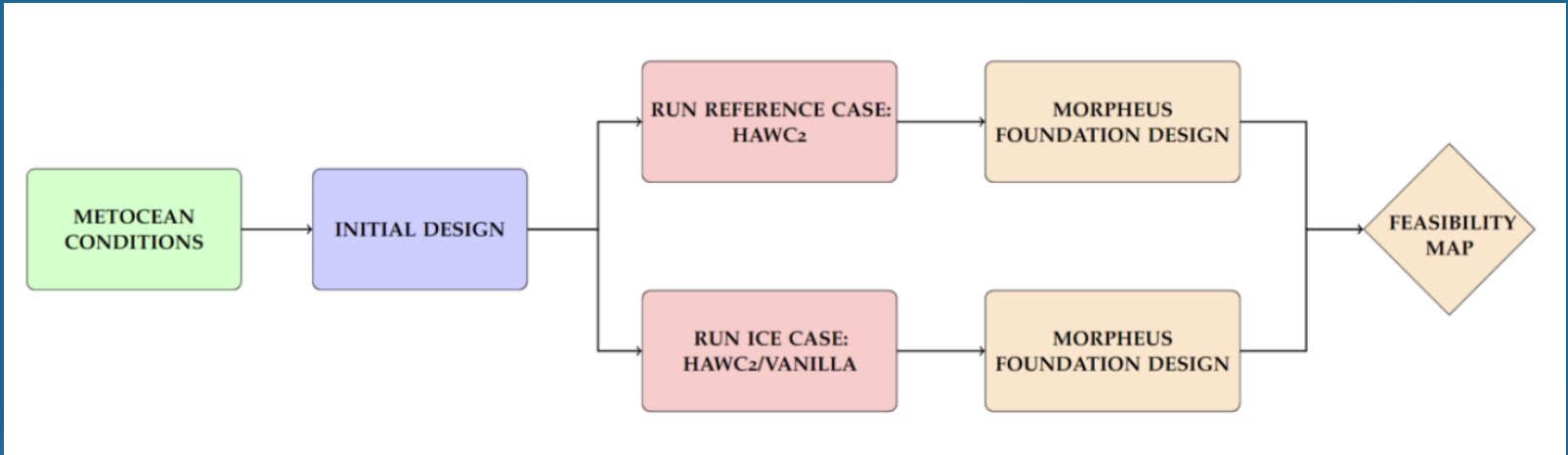
- Expensive fabrication
- Labour-intensive
- Limited water depth

Ice cones



Gravity based structures

Research – Defining a feasibility map



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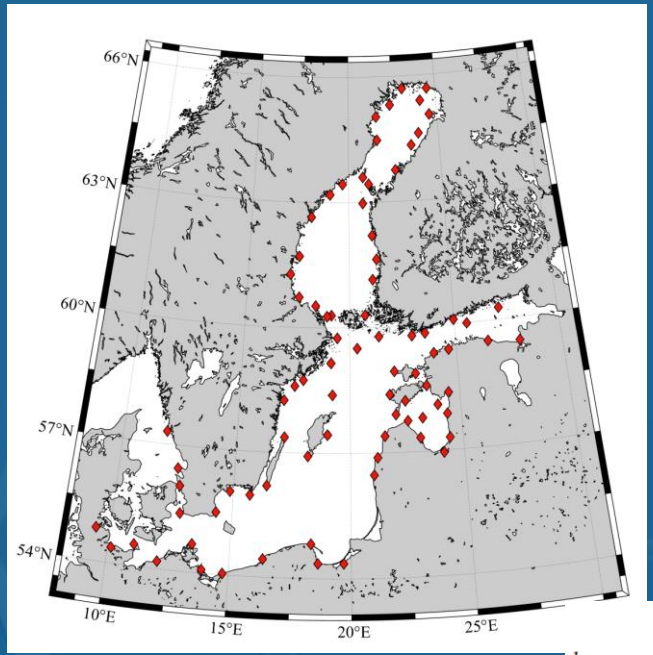
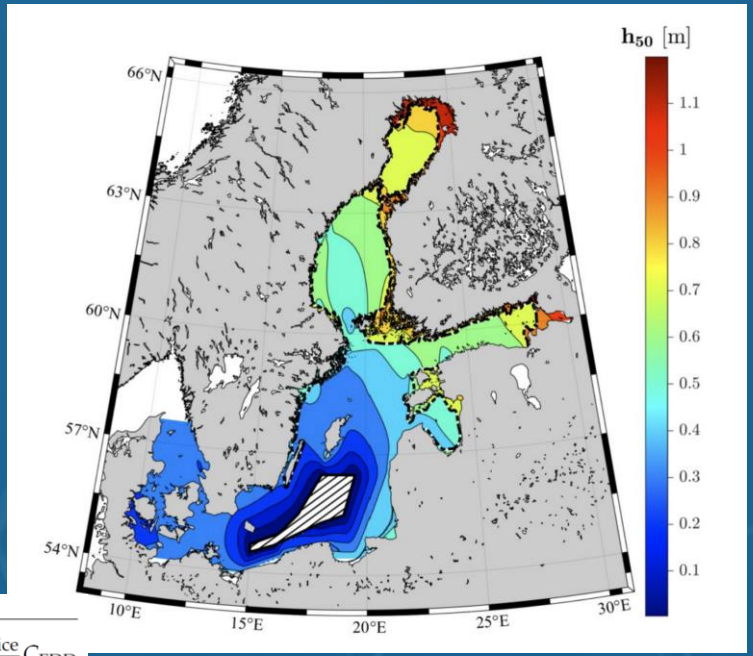
Impact of sea ice

Data on ice thickness is scarce, but data on air temperature is not!





$$h_{\text{ice}} = \sqrt{\omega \frac{2k_{\text{ice}}}{\rho_{\text{ice}} \ell} C_{\text{FDD}}}$$

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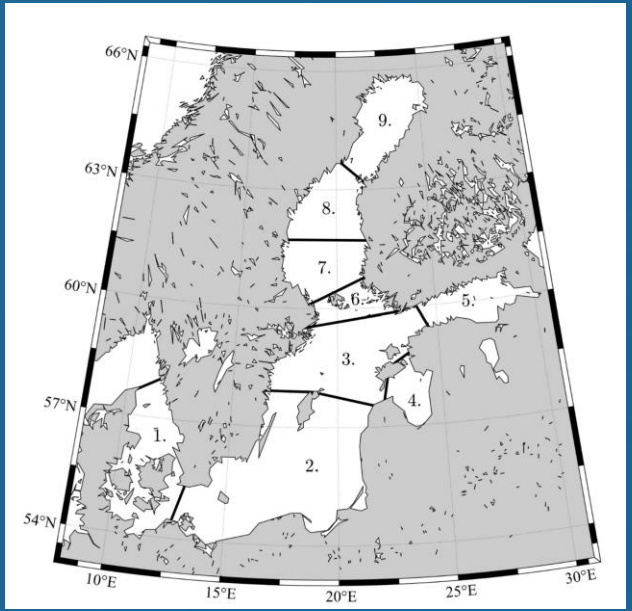
Identified regions

1. Danish Straits (DS)
2. Baltic Proper South (BPS)
3. Baltic Proper North (BPN)
4. Gulf of Riga (GOR)
5. Gulf of Finland (GOF)
6. Archipelago Sea (ARS)
7. Bothnian Sea South (BSS)
8. Bothnian Sea North (BPN)
9. Bay of Bothnia (BOB)



Region	h_{50} [m]	$C_{R;1}$ [MPa]	Depth [m]	$v_{wind;50}$ [m s^{-1}]	$H_{S;50}$ [m]	D_{ice} [days per lifetime]
Danish Straits	0.40	0.88	19	45.06	6.17	9.6
Baltic Proper S.	0.45	0.86	65*	43.44	12.43	11.9
Baltic Proper N.	0.50	0.88	65*	43.88	12.96	73.3
Gulf of Riga	0.55	0.94	26	39.19	9.23	197.6
Gulf of Finland	0.95	0.95	37	35.96	6.44	198.0
Archipelago Sea	0.75	0.92	23	40.28	6.55	96.9
Bothnian Sea S.	0.65	0.92	50	40.72	12.53	228.0
Bothnian Sea N.	1.00	0.94	65*	41.07	11.26	299.8
Bay of Bothnia	1.25	0.98	42	37.70	9.75	352.5

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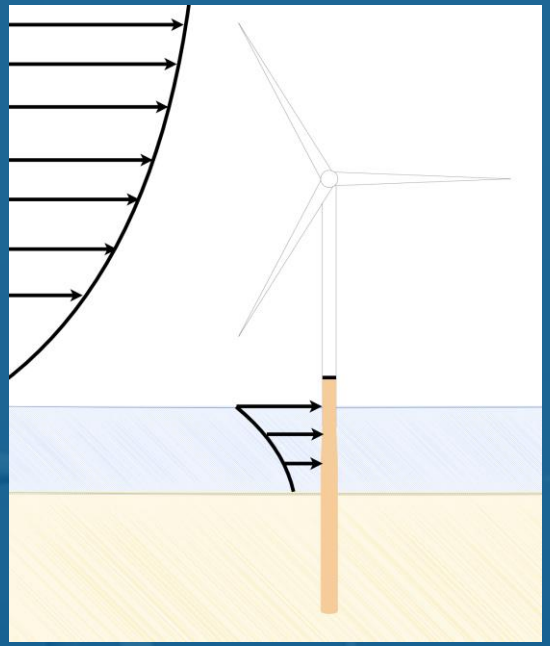
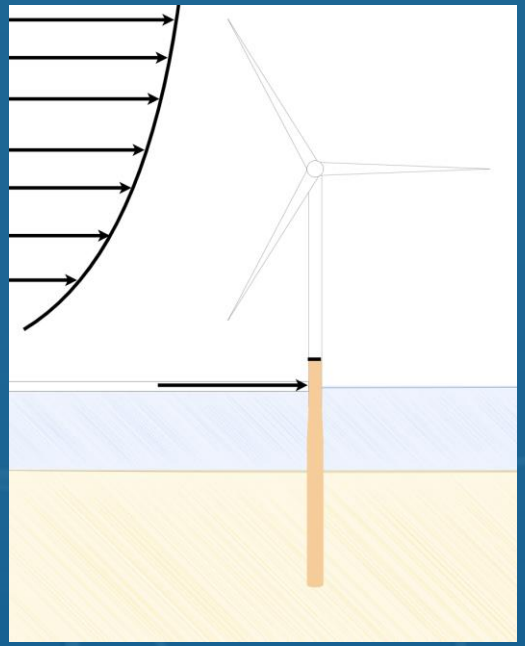
HAWC2, VANILLA & Morpheus

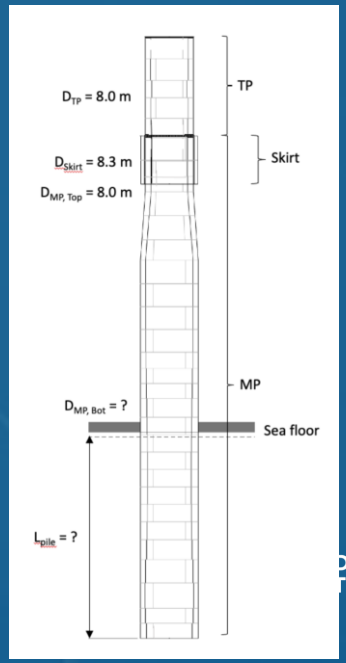
HAWC2
- Code for aero-elastic simulations
- Load generation

VANILLA
- Phenomenological ice crushing model

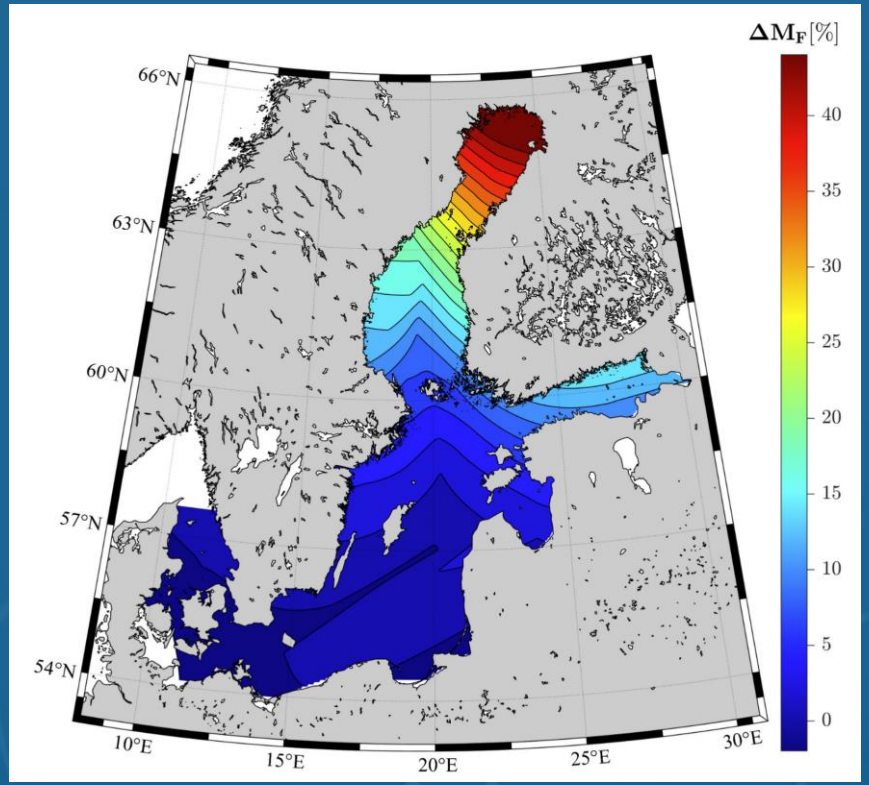
MORPHEUS
- Holistic wind farm design
- Foundation optimization







Results – weight increase map



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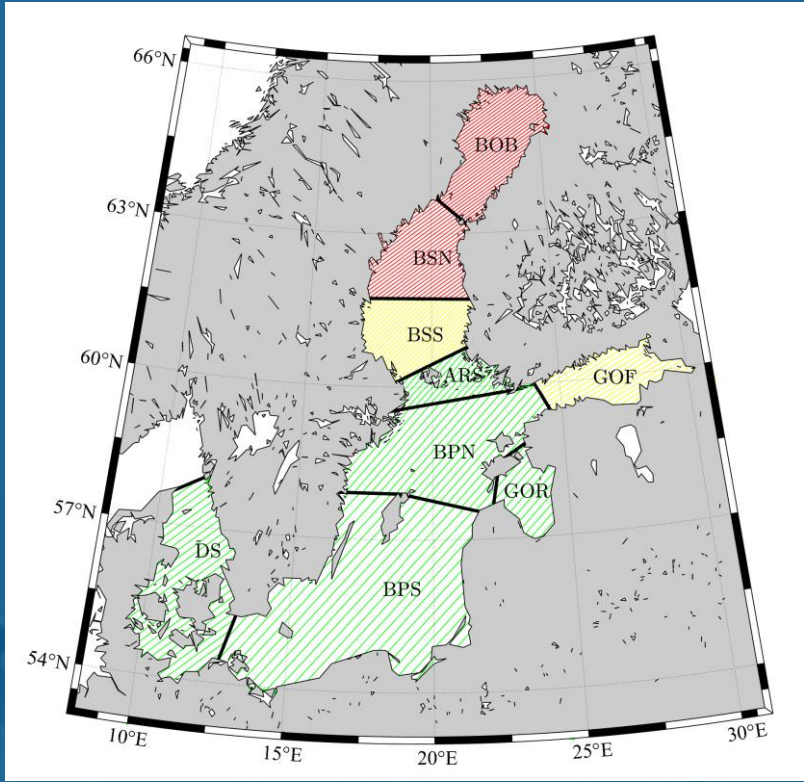
Results – feasibility map

- Exceedance of maximum foundation weight
- Exceedance of can thickness/can weight
- Likely economically infeasible



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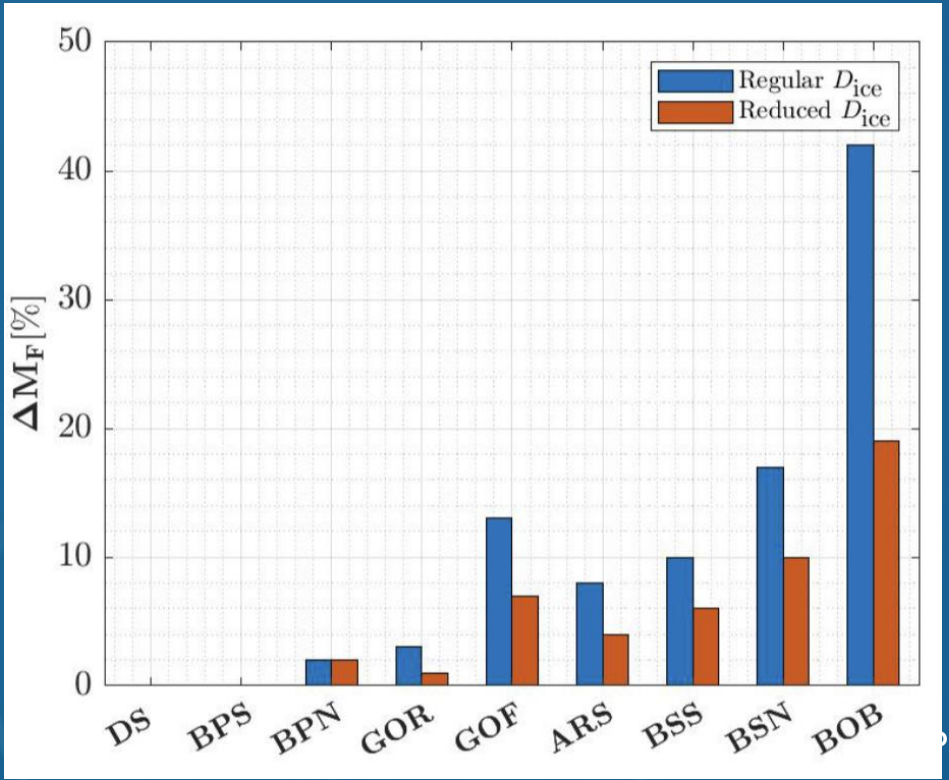
Conclusions

- Fatigue loads governing for design
- ICR/FLI largely responsible for damage
- Emphasis on accurate ice data

- Monopiles are feasible in DS, BPS, BPN, GOR, ARS
- BSS and GOF feasibility depends on alternative options
- Infeasible in BSN and BOB
- Accurate ice data is extremely valuable!



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THANK YOU

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